Terrain Surface Codes for an All-Season, Off-Road Ride Motion Simulator

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INTRODUCTION

Researchers at the U.S. Army Engineer Research and Development Center (ERDC) and U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) are collaborating to improve Army ground vehicle modeling and simulation capabilities. This work, part of the U.S. Army Science and Technology Objective (STO) IV.GC.2003.01, "High-Fidelity Ground Platform and Terrain Modeling (HGTM)," is centered on the TARDEC virtual evaluation suite [1], which includes their ride motion simulator (Figure 1). One of the goals of this effort is to embed ERDC vehicle–terrain interaction algorithms [2] within the simulator software, such that they provide the forces between vehicle components (tires or tracks) and the terrain. These algorithms require associated terrain surface conditions, which are functions of weather, topography, and terrain attributes.

This paper describes the approach taken to relate terrain mechanics properties with the terrain database in sufficient detail to support the TARDEC Ride Motion Simulator and, additionally, allow consistency when interacting with Semi-Automated Force (SAF) vehicles within the OneSAF Testbed Baseline (OTB), OneSAF Objective System (OOS), and potentially other simulators or simulations.

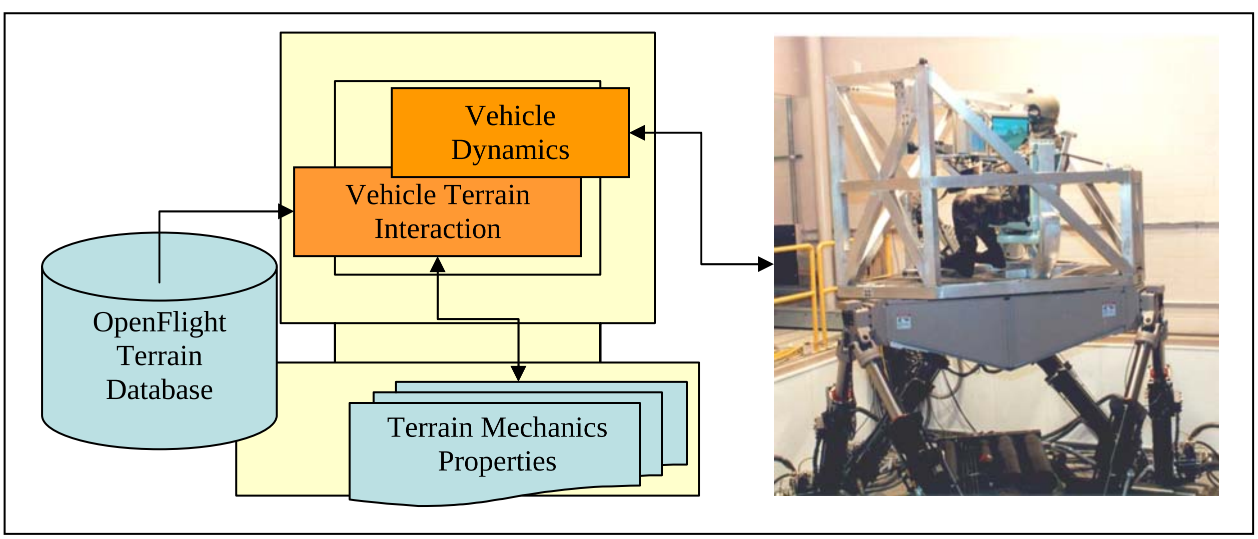

Figure 1. The TARDEC ride motion simulator.

BACKGROUND

Vehicle–terrain interaction algorithms (terramechanics software) describe the vehicle dynamics model interactions with the terrain database. The terrain data and the Ride Motion Simulator visuals are based on an OpenFlight database. The desire is to use the OpenFlight database to store terrain attributes, which can be referenced to the parameters required by the terramechanics model. The attributes important for predicting the distribution of all-season terrain parameters are soil type, drainage, slope, aspect, canopy, and elevation. Bullock [3] developed methodology to infer soil strength values from soil type, wetness index, geographic location, and a seasonal parameter (dry, average, wet, wet-wet). Following this methodology and adding capability to spatially distribute snow and thawing/frozen ground, a more distinct value of climate impact (e.g. monthly, weekly, or even hourly) is indexed to a set of principal terrain mechanics parameters. Microclimate considerations suggest that soil type, wetness or drainage index, slope, aspect, and canopy should provide a unique set of indices that, when combined with climatologic and geographic information, will allow estimates of the required terrain mechanics properties (Table 1). Table 1 includes the corresponding equivalent Environmental Data Coding Specification (EDCS) attribute names and definitions, which are in the OOS terrain database.

Table 1. Terrain mechanics properties required for the HGTM terramechanics code.

HGTM Name	EDCS[1] Name	EDCS Definition
Terrain Condition[2] (Normal, Slippery, Frost, Snow, Ice)	SURFACE_SLIPPERY	Indication that a surface is slippery.
	FROZEN_SURFACE_COVER_TYPE	The type of frozen water present (none, ice, snow, snow over ice, slush, etc.)
Soil Type	SOIL_TYPE	The Unified Soil Classification System (USCS) soil type.
	TERRAIN_TRANSPORTATION_ROUTE_SURFACE_TYPE	The physical surface composition of a road, runway or other surface intended to support the movement of a vehicle.
Rating Cone Index or Cone Index at 0–6 inches	SOIL_CONE_INDEX_QB_MEASUREMENT_DEPTH	Soil cone index at a depth: [0,15], [15,30] where measurement depths are in centimeters.
Rating Cone Index or Cone Index at 6–12 inches		
Snow Depth	SNOW_ONLY_DEPTH	The depth of the snow, which may be over terrain, ice, or floating ice.
Snow Density	SNOW_DENSITY	The density of accumulated snow on an object.
Frost Depth	FROZEN_SOIL_LAYER_BOTTOM_DEPTH	The depth from the terrain to the base of a layer of frozen soil.
Thaw Depth	FROZEN_SOIL_LAYER_TOP_DEPTH	The depth from the terrain to the top of a layer of frozen soil.

[1] Environmental Data Coding Specification http://www.sedris.org
[2] Described by more than one EDCS name

In order to make the terramechanics code easily updated to more complex models, and because there is not enough available storage space in the OpenFlight or Compact Terrain Database (CTDB) file formats for all these values, an index or "type," which can be related to a unique set of these values based on time of year, will allow greater flexibility to model terrain effects without the need to develop or recompile terrain databases for each desired variation in season or weather. Currently there is space in the OpenFlight format for a 16-bit integer, allowing 65,536 combinations of types. The number of types allowed in CTDB (version 7) is at least 512 (9 bits). The current intent is to develop the OpenFlight database and then convert it to CTDB format. This code, as an attribute to each polygon in the database, will need to classify

1) Soil Type (23)
2) Drainage Index (6)
3) Slope and Aspect Class (27)
4) Canopy Index (8).

For each combination of these parameters (HGTM terrain code), within ranges of elevation, and that occur within a terrain database, there will be a corresponding set of terrain mechanics properties in a look-up table (terrain mechanics properties table). This allows, for example, different tables to be developed for each month of the year (based on climatologic data for the terrain database location). Alternatively, the table could approximate the effects of a specific weather scenario, or actual measurements. Conceptually, the table could be changed during the simulation to bring in dynamic weather effects on the terrain.

The following discusses the values selected to determine this terrain attribute code.

DETERMINATION OF SOIL TYPE CODES

The Unified Soil Classification System (USCS) soil code was used to associate soil behavior to vehicle performance for off-road applications. Pavement, shallow (fordable) water, and deep water are also included. The discussion below presents several representations of soil or terrain coding for different modeling and simulations applications followed by the scheme selected for this (HGTM) application.

The OneSAF TestBed operates on a CTDB, currently version 7 or higher. Describing terrain conditions has been a continuous issue with the CTDB format, and a review of the changes made as the CTDB evolved shows that almost every version change included a new way to represent the soil and its strength or wetness. The following was extracted from http://www.onesaf.org/extint/fdd/modsaffd.html for CTDB version 7:

> *Attributes can be specified for terrain elements in addition to the SIMNET mobility index.*
>
> *At a minimum, the CCTT soil type [(FACC) code (STP)], Surface Material Code (SMC), and Surface Wetness Condition (SWC) are associated with each terrain element.*
>
> *Other FACC attributes can be associated with terrain using the "correction_files" mechanism of the "recompile" program.*
>
> *FACC attributes of a convex polygon can be changed by the recompile program using the "correction_files" mechanism. Specified attributes are changed to the new value while other attributes of the terrain retain their original value.*

Birkel [4] developed a good summary of the different soil codes available within the CTDB. Tables 2 and 3 show the codes and descriptions for SIMNET and CCTT soil codes. Also, during one of the Envirofed efforts [5], space was made for Cone Index 0–6, Cone Index 6–12, Soil Moisture 0–6, and Soil Moisture 6–12. These can be set using DTSIM (with JSAF); however it is not yet known whether they can be set using the Terrasim software (www.terrasim.com) used to convert the OpenFlight to CTDB. Note that these four integers (Cone Index 0–6, Cone Index 6–12, Soil Moisture 0–6, and Soil Moisture 6–12) along with a soil type are used to define soil properties for use by version 1.0 of STNDMob. STNDMob (libsoilmobility) provides JVB-OTB with maximum vehicle speeds based on terrain, vehicle type, and preprocessed NRMM data.

Table 2. SIMNET soil types [4].

Index	Soil Type	Description
0	SOIL_DEFAULT	Unknown type of soil
1	SOIL_ROAD	Asphalt or other hard surface
2	SOIL_RCI250	Packed soil or dirt road
3	SOIL_RCI050	Soft sandy soil
4	SOIL_DEEP_WATER	Impassable deep water
5	SOIL_SHALLOW_WATER	Passable shallow water
6	SOIL_MUD	Muddy soil
7	SOIL_MUDDY_ROAD	Wet dirt road
8	SOIL_ICE	Slick ice surface
9	SOIL_SWAMP	Very soft surface
10	SOIL_FORESTED	Canopy or forested area
11	SOIL_US_RAILROAD	Railroad with U.S. specifications
12	SOIL_EURO_RAILROAD	Railroad with European specs
13	SOIL_ROCKY	Small rocks ≤ 18 inches
14	SOIL_BOULDERS	Large boulders 6 feet high
15	SOIL_FLIMSY	Indoor surface for dismounted infantry
15[1]	SOIL_NO_GO	Terrain that is not traversable
[1] Note this index has two meanings, depending on the terrain database.		

Table 3. CCTT terrain codes [4].

Terrain Code	USCS Soil Type or Surface Type	Qualitative Soil Strength	CI /RCI
1	SP, SW	Soft	35
2	SP, SW	Average	100
3	SP, SW	Hard	130
4	SM, SC, ML, ML, CH, MH, OL, OH	Very Soft	25
5	GW, GP, GM, GC, SM, SC, CL, ML, CH, MH, OL, OH	Soft	35
6	SM, SC, CL, ML, CH, MH, OL, OH	Average - Soft	50
7	SM, SC, CL, ML, CH, MH, OL, OH	Average - Hard	80
8	SM, SC, CL, ML, MH, OL	Hard	130
9	GW, GP, GM, GC, SM, SC, CL, ML, MH, OL	Very Hard	280
10	SM, SC, CL, ML, MH, OL	Hard (Slippery)	130
11	SM, SC, CL, ML, MH, OL	Very Hard (Slippery)	280
12	CH, OH	Hard	130
13	CH, OH	Very Hard	280
14	CH, OH	Hard (Slippery)	130
15	CH, OH	Very Hard (Slippery)	280
16	PT	Dry Peat	40
17	GW, GP, GM, CH, Rock	Dry Loose Surface Road	300
18	GW, GP, GM, CH, Rock	Wet Loose Surface Road	300
19	NO-GO	Swamps, Bogs, etc.	10
20	Concrete, Asphalt	Dry Pavement	600
21	Concrete, Asphalt	Wet Pavement	600
22	SM, SC, CL, ML, CH, MH, OL, OH	Brushland - Medium	80
23	SM, SC, CL, ML, CH, MH, OL, OH	Brushland - Hard	280
24	SM, SC, CL, ML, CH, MH, OL, OH	Brushland - Medium (Slippery)	80
25	SM, SC, CL, ML, CH, MH, OL, OH	Brushland – Hard (Slippery)	280
26	Water with (Silts and Clays) Bottom	Depth 16 inches	25
27	Water with (Silts and Clays) Bottom	Depth 33 inches	25
28	Water with (Silts and Clays) Bottom	Depth 60 inches	25
29	Water with (Bedrock, Gravel, Paved) Bottom	Depth 16 inches	300
30	Water with (Bedrock, Gravel, Paved) Bottom	Depth 33 inches	300

UAMBL and ERDC-GSL used 9 bits of the CTDB normally used for SIMNET soil types and CCTT soil types to allow 512 soil/terrain codes to define soil properties via a lookup table embedded in the libstdmob code (a pure C version of libsoilmobility in the OF/OTB). These terrain codes are obtained from the 9 bits in the CTDB for the cctt_simnet_soil and ctdb_soil values [cctt_simnet_soil = (ctdb_soil & 0x1ff)]. Table 4 shows the codes and the values developed for a specific terrain file, with these codes both climate- and location-dependent.

Table 4. A sample of UAMBL terrain codes for the libstdmob implementation of STNDMob.

Terrain Code	Soil Type	Veg. Code	Cone Index 0–6 inch	Cone Index 6–12 inch	Description
0	7	0	300	300	Default
1	2	0	300	300	Asphalt
2	7	0	300	300	Packed soil or dirt road
2	10	0	300	300	Packed soil or dirt road. Used stone for SMC.
3	6	0	80	80	Soft sandy soil. Used sand for SMC.
4	0	0	0	0	Impassable deep water
5	7	0	100	100	Passable shallow water
6	7	0	25	80	Muddy soil
7	7	0	25	300	Muddy road
8	7	0	100	100	Slick ice surface. Ice for SMC.
9	12	2	25	50	Impassable swamp in OTB
10	12	2	100	100	Forested area in OTB
11	0	0	0	0	Railroad with U.S. specifications
12	0	0	0	0	Railroad with European specs
13	2	1	300	300	Small rocks ≤ 18 inches high
14	2	2	300	300	Large boulders 6 feet high
15	7	2	25	5	Terrain that is not traversable
16	6	0	80	80	Poorly graded/uniform sands gravelly sand mix
17	7	0	80	80	Silty sand/silty gravelly sands
18	8	0	100	100	Clayey sands/clayey gravelly sands
19	9	0	75	75	Silts/very fine sands
20	10	0	150	150	Low-plasticity clays
21	12	0	150	150	Highly plastic clays and sandy clays
22	9	2	100	100	Soil in and around orchard
23	9	1	100	100	Soil in and around vineyard
24	7	0	300	300	Soil in and around urban area
25	7	0	300	300	Soil in and around town area
26	11	1	25	75	Passable swamp
27	7	0	300	300	Soil in and around farm buildings - not cultivated fields
28	7	0	300	300	Pipeline

For our application, there are 23 "HGTM soil types" of interest, which are shown in Table 5 along with their relation to other model representations. Because the terrain database must be capable of representing all-season conditions, several classes of roads were added. These are listed as types 17, 18, 21, 22 and 23 in Table 5. This allows us to differentially apply the seasonal changes to other trafficable terrain types (i.e. roads), specifically, to pack, plow, or traffic the snow based on road classification.

DRAINAGE INDEX

Drainage index, Table 6, was initially described by Bullock [3] as a wetness index. It is an indication of how easily the soil can dry out or become saturated based on drainage characteristics of the soil. This is important because the soil strength (represented as a cone index) is directly related to soil moisture. The drainage index values presented in Table 6 correspond to the Environmental Data Coding Specification (EDCS) attribute EAC_SOIL_WETNESS_CATEGORY enumerations as shown.

Table 5. Soils types for different models or databases.

HGTM Soil Type	Libsoilmobility		OOS - EDCS SOIL_TYPE USCS Soil Type Enumerations and TERRAIN_ROUTE_TYPE	NRMM USCS Soil and Road Types and (NRMM Soil Group Code)
	Index	USCS Soil Type		
1	1	GW	GW	GW (6)
2	2	GP	GP	GP (6)
3	3	GM	GM	GM (4)
4	4	GC	GC	GC (1)
5	5	SW	SW	SW (6)
6	6	SP	SP	SP (6)
7	7	SM	SM	SM (4)
8	8	SC	SC	SC (1)
9	9	ML	ML	ML (3)
10	10	CL	CL	CL (3)
11	11	OL	OL	OL (3)
12	12	CH	CH	CH (2)
13	13	MH	MH	MH (2)
14	14	OH	OH	OH (2)
15	15	Pt	PT	Pt (7)
			ML_AND_CL	MLCL (3)
			SM_AND_SC	SMSC (4)
			EVAPORITES	
				GMGC (4)
16				Rock (5)
17			SECONDARY_ROAD	Secondary
18			PRIMARY_ROAD	Primary
			SUPER_HIGHWAY	Super Highway
19 - Shallow water				
20 - Deep water				
21 - Constructed, well-maintained gravel road with well-drained, good gravel surface				
22 - Constructed, marginal gravel road (constructed, but not always maintained or well drained)				
23 – “Two-track” road/trail, made of natural soil material (not constructed - but compacted from traffic)				

SLOPE AND ASPECT CLASSES

Aspect (or azimuth) affects the amount of incident solar radiation, thus influencing soil drying or snow melting. Aspect categories based on discussions with subject matter experts led to the selection of aspect classes based on 36-deg increments (10 categories). Slope categories based on vehicle mobility analyses [6, 7] are shown in Table 7, along with the representative values used in the terrain state analysis by FASST [8]. However, for the real-time simulator, the impact of slope on vehicle performance is explicitly calculated by the vehicle dynamics code, and what is needed here is the effect of slope on terrain properties, specifically, the spatial distribution of snow cover. Analysis using an analytical model of snowmelt and accumulation, including solar energy input, led to the combination of slope and azimuth shown in Figure 2 and in Table 8 to account for the spatial distribution of snow and freeze/thaw.

CANOPY

The amount and type of vegetation canopy will have an effect on the amount of solar energy that is imposed on the ground surface, impacting surface drying, freeze/thaw, and snowmelt. We used six classes to represent the vegetation with respect to canopy and solar loading (or shading of the surface): open, mixed light, deciduous light, deciduous dense, coniferous dense, and mixed dense. Trails (a soil or gravel, non-paved roadway) with and without a canopy were added to take advantage of two free indices, and to allow differentiation of soils that make up a trail (soils on trails may be of the same type as others in the area, but have a different terrain condition (packed or stronger soil or snow). A little information is lost regarding the amount of canopy, but the ability to differentiate a trail from surrounding soil is gained.

Table 6. Drainage index categories [3].

Drainage Index	Potential Wetness	Depth to Water Table	Depth of Wetting	General Characteristics of Sites	EDCS Attribute Symbolic Constant: EAC_SOIL_ WETNESS_CATEGORY (corresponding enumerations)
0	Arid	Indeterminable	Less than 1 ft	Located in desert regions.	PERENNIALLY_DRY
1	Dry	Indeterminable	1–4 ft	Steeply sloping denuded or severely eroded and gullied.	
2	Average	More than 4 ft	More than 4 ft	Well-drained soil with no restricting layers or pans; fair to good internal and external drainage. Slope may be flat to steep.	MOIST
3	Wet	1–4 ft	To water table	Soil not well drained. Restricting layers or deep pans may be present. May occur at base of slopes, on terraces, upland flats, or bottom lands.	WET
4	Saturated	Less than 1 ft	To water table	Sites waterlogged or flooded at least part of the year. Bottomlands subject to frequent overflow. Upland with poor drainage or shallow pans. Slopes with very poor drainage.	SATURATED
5	Saturated	Zero (surface)	Complete	Areas perennially waterlogged. No change in water content or soil strength.	WATERLOGGED

Table 7. Mobility slope categories.

Category index	Range (%)	Value Used in Terrain State Analysis (%)
0	0–2	1
1	> 2 and ≤ 5	3.5
2	> 5 and ≤ 10	7.5
3	> 10 and ≤ 20	15
4	> 20 and ≤ 40	30
5	> 40 and ≤ 60	50
6	> 60	60

<table>
<tr><th>Slope (degrees)</th><th colspan="10">Slope/Aspect Class</th></tr>
<tr><td>0–3</td><td colspan="10">0</td></tr>
<tr><td>3–7</td><td>1</td><td rowspan="2">5</td><td rowspan="4">7</td><td rowspan="2">8</td><td>10</td><td>14</td><td rowspan="2">18</td><td rowspan="4">20</td><td rowspan="2">21</td><td>23</td></tr>
<tr><td>7–10.5</td><td>2</td><td>11</td><td>15</td><td>24</td></tr>
<tr><td>10.5–15</td><td>3</td><td rowspan="2">6</td><td rowspan="2">9</td><td>12</td><td>16</td><td rowspan="2">19</td><td rowspan="2">22</td><td>25</td></tr>
<tr><td>≥ 15</td><td>4</td><td>13</td><td>17</td><td>26</td></tr>
<tr><td colspan="11">0 36 72 108 144 180 216 252 288 324 360</td></tr>
<tr><td colspan="11">Azimuth (degrees)</td></tr>
</table>

Figure 2. Graphical representation of the slope and aspect classes used in the terrain code for spatially distributing snow properties.

Table 8. Slope/aspect classes.

Slope/ Aspect Class	Slope Range (degrees)	Azimuth Range (degrees)	Slope/ Aspect Class	Slope Range (degrees)	Azimuth Range (degrees)
0	≥ 0 and < 3	0 to 360	14	≥ 3 and < 7	≥ 180 and < 216
1	≥ 3 and < 7	≥ 0 and < 36	15	≥ 7 and < 10.5	≥ 180 and < 216
2	≥ 7 and < 10.5	≥ 0 and < 36	16	≥ 10.5 and < 15	≥ 180 and < 216
3	≥ 10.5 and < 15	≥ 0 and < 36	17	≥ 15	≥ 180 and < 216
4	≥ 15	≥ 0 and < 36	18	≥ 3 and < 10.5	≥ 216 and < 252
5	≥ 3 and < 10.5	≥ 36 and < 72	19	≥ 10.5	≥ 216 and < 252
6	≥ 10.5	≥ 36 and < 72	20	≥ 3	≥ 252 and < 288
7	≥ 3	≥ 72 and < 108	21	≥ 3 and < 10.5	≥ 288 and < 324
8	≥ 3 and < 10.5	≥ 108 and < 144	22	≥ 10.5	≥ 288 and < 324
9	≥ 10.5	≥ 108 and < 144	23	≥ 3 and < 7	≥ 324 and < 360
10	≥ 3 and < 7	≥ 144 and < 180	24	≥ 7 and < 10.5	≥ 324 and < 360
11	≥ 7 and < 10.5	≥ 144 and < 180	25	≥ 10.5 and < 15	≥ 324 and < 360
12	≥ 10.5 and < 15	≥ 144 and < 180	26	≥ 15	≥ 324 and < 360
13	≥ 15	≥ 144 and < 180			

The OpenFlight format allows each polygon to have a ground material type. These canopy indices are combined with the other OpenFlight terrain codes to obtain the actual surface conditions. OpenFlight also allows other codes (for example, Evans and Sutherland Identifiers (ESID), which is an extension of the DFAD codes developed by Evans and Sutherland), but these can generally be mapped to the DFAD codes [9]. The eight HGTM Canopy Indices are cross-referenced to the OpenFlight DFAD classes of interest (those indicating some type of vegetation) in Table 9.

ELEVATION EFFECTS

Elevation can influence the amount of precipitation an area receives, and there are models to estimate this effect; snowfall is particularly affected. Elevation is not included in the HGTM terrain surface type; however, for elevation ranges dependent on the weather condition scenario or measured data, multiple sets of the HGTM terrain mechanics tables can be created and linked to the terrain in the elevation query that occurs in real time within the Vehicle Terrain Interface code [2].

Table 9. Vegetation and canopy codes.

HGTM		OpenFlight	
Index	Canopy Description	DFAD FIC Classes	
0	Open	902	PHYSIOGRAPHY - Soil (General)
0	Open	906	Sand/Desert
0	Open	907	Sand Dune/Sand Hill
1	Mixed Light	908	Marsh, Wetland, Swamp, Bog
0	Open	909	Rice Field
0	Open	912	Rocky Rough Surface
0	Open	913	Dry Lake
0	Open	916	Cleared Ways
0	Open	934	Salt Pan
1	Mixed Light	950	Vegetation (general)
2	Deciduous Light	951	Orchard/Hedgerow
3	Deciduous Dense	952	Trees, Deciduous
4	Conifers Dense	953	Trees, Evergreen
5	Mixed Dense	954	Trees, Mixed (Evergreen and Deciduous)
0	Open	955	Tundra
2	Deciduous Light	956	Vineyard/Hops
6	Non-canopy Trail		Trails Without a Canopy
7	Canopied Trail		Trails With a Canopy

The HGTM terrain properties table is configured to be easily developed or modified using a spreadsheet. A list of all of the HGTM terrain surface types is obtained from the OpenFlight database, within specified elevation ranges. Table 10 shows how the hexadecimal HGTM terrain surface code is translated in the spreadsheet.

Table 10. Conversion of the hexadecimal code to HGTM surface types/classes.

		Bit Code				Decimal Equivalents				HGTM Surface Type/class			
Hexi-decimal	Decimal	Soil Type (5 bits)	Drainage Index (3 bits)	Slope-Aspect Class (5 bits)	Canopy Index (3 bits)	Soil	Drainage	Slope-Aspect	Canopy	Soil	Drainage	Slope-Aspect	Canopy
1B90	7056	00101	011	10010	000	5	3	18	0	SW	Wet	19	Open
1A00	6656	00101	010	00000	000	5	2	0	0	SW	Avg	1	Open
1B01	6913	00101	011	00000	001	5	3	0	1	SW	Wet	1	Mixed Light
B09	2825	00001	011	00001	001	1	3	1	1	GW	Wet	2	Mixed Light
B0B	2827	00001	011	00001	011	1	3	1	3	GW	Wet	2	Decid Dense
2B0B	11019	01011	011	00001	011	11	3	1	3	OL	Wet	2	Decid Dense
3B15	15125	01101	011	00010	101	13	3	2	5	MH	Wet	3	Mixed Dense
315	789	00010	011	00010	101	2	3	2	5	GP	Wet	3	Mixed Dense
414	1044	00010	100	00010	100	2	4	2	4	GP	Sat_4	2	Conif Dense

These terrain codes are permanent fixtures of the terrain polygons and are used to assign terrain strength properties to the polygon by linking to a terrain mechanics table that is based on the season or weather, time of year, or even time of day. Table 11 shows the file format for terrain properties indexed with the hexadecimal code. These terrain mechanics properties are used in the calculation of the forces at the vehicle/terrain interface, as illustrated in Figure 1. Because of this modular set up of the interface and terrain mechanics table, the tables can be easily changed to accommodate different parameters as the interface code is updated to more sophisticated vehicle–terrain models.

An application of this methodology for a seasonal terrain database, the Vermont National Guard's Ethan Allen Firing Range in northern Vermont, is presented in Shoop et al. [10].

Table 11. Sample terrain properties table with three ranges of elevation (elevation is in meters).

Elevation = < 500										
Hex Code	**Decimal Code**	**Terrain Surface Condition**	**Soil Type**	**Soil Moisture Code**	**RCI 0–6**	**RCI 6–12**	**Surface Cover Depth**	**Snow Density**	**Frost Depth**	**Thaw Depth**
1B90	7056	NCG	SW	NOR	150	300	0	0	0	0
1A00	6656	NCG	SW	NOR	150	300	0	0	0	0
1B01	6913	NCG	SW	NOR	150	300	0	0	0	0
B09	2825	NCG	GW	NOR	150	300	0	0	0	0
B0B	2827	NCG	GW	NOR	150	300	0	0	0	0
2B0B	11019	SFG	OL	SLP	100	200	0	0	0	0
3B15	15125	SFG	MH	SLP	80	200	0	0	0	0
315	789	NCG	GP	NOR	250	300	0	0	0	0
Elevation < 1500										
1B90	7056	SNO	SW	AVG	150	300	5	0.3	30	0
1A00	6656	SNO	SW	AVG	150	300	10	0.3	30	0
1B01	6913	SNO	SW	AVG	150	300	15	0.3	30	0
B09	2825	FCG	GW	AVG	150	300	0	0	30	2
B0B	2827	SNO	GW	AVG	150	300	10	0.3	30	0
2B0B	11019	SNO	OL	DRY	80	200	10	0.3	0	0
3B15	15125	FFG	MH	SAT	75	100	0	0	30	0
315	789	FCG	GP	SAT	75	100	0	0	30	0
Elevation ≥ 1500										
1B90	7056	SNO	SW	DRY	300	300	20	0.25	30	0
1A00	6656	SNO	SW	DRY	300	300	30	0.25	30	0
B09	2825	SNO	GW	DRY	300	300	20	0.25	30	0
2B0B	11019	SNO	OL	DRY	300	300	10	0.25	30	0
3B15	15125	SNO	MH	DRY	300	300	5	0.25	30	0
315	789	SNO	GP	DRY	300	300	5	0.25	30	0

SUMMARY

A method of linking seasonal terrain conditions to an OpenFlight database, without the need to recompile the terrain database, is presented. The seasonal terrain data support high-resolution, real-time terrain interaction of a vehicle ride motion simulator. Implementation of terrain-related attributes to support both the simulator and SAF models is illustrated in this paper.

ACRONYMS

CCTT	Combined Arms Tactical Training System
DFAD	Digital Feature Analysis Database
DTSIM	Dynamic Terrain Simulator
EDCS	Environmental Data Coding Specification
EnviroFed	Environment Federation
ERDC-GSL	Engineer Research and Development Center, Geotechnical and Structures Laboratory
ESID	Evans and Sutherland Identifiers (for terrain features)
HGTM	U.S. Army Science and Technology Objective IV.GC.2003.01, "High-Fidelity Ground Platform and Terrain Modeling" project
JSAF	Joint Semi-Automated Forces
JVB-OTB	Joint Virtual Battlespace version of OTB
OF/OTB	Objective Force OTB
OOS	OneSAF Objective System
OTB	OneSAF Testbed Baseline
NRMM	NATO Reference Mobility Model
SIMNET	Simulator Networking
STNDMOB	Standard mobility, a set of code based on NRMM, which predicts the maximum speed possible for a ground vehicle for a given set of terrain properties.
UAMBL	Unit of Action Mounted BattleLab

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